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Regeneration, Growth and Development of *Picea glauca* under *Populus* spp. Canopy in the Boreal White and Black Spruce Zone

by

Richard Kabzems, P. Ag.
J. Daniel Lousier, P. Ag., R. P. Bio.

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For additional copies and/or further information about the Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II, contact:

Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 363-0600

or

B.C. Ministry of Forests
Forest Science Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

EXECUTIVE SUMMARY

This report describes results of a 2-year project to investigate some of the factors affecting the regeneration, growth, and development of white spruce (*Picea glauca*) under aspen or balsam poplar (*Populus* spp.) canopies in the Boreal White and Black Spruce Biogeoclimatic Zone near Fort Nelson, B.C.

Five upland sites and one alluvial site with white spruce under aspen or balsam poplar were sampled and described for vegetation, soil temperature, soil moisture, soil nutrients, white spruce foliar nutrients, and site index.

Were there differences in soil temperature between sites?

Yes. The alluvial site had a greater accumulation of soil degree days (0°C base) than the upland sites. The growing season pattern of soil temperatures was different for the alluvial site. Daily mean soil temperatures were greater than upland sites until mid-August, after which temperatures declined to below those of upland sites. At the 50 cm depth in mineral soil, the upland site with coarse-textured soil had greater degree days than upland sites on fine-textured soils. Differences in soil temperatures were related to canopy structure, successional stage, depth of forest floor, soil texture, and soil moisture content of the sites.

Were there differences in soil moisture between sites?

Probably. However, differences could not be quantified in 1989 because of problems with the measuring device.

Were there differences in nutrient status between sites?

Yes. Significant differences in soil total nitrogen, sulfate sulfur, and exchangeable base quantities existed between the sites. Interactions between temperature, moisture, and quality of organic matter may determine important differences in nutrient cycling and nutrient availability between sites. Foliar nitrogen content of white spruce on Site 5 was significantly greater than that of white spruce on sites which had greater total nitrogen quantities in the soil.

Did a residual aspen canopy affect planted white spruce seedling performance?

White spruce seedlings planted under a residual aspen canopy were significantly shorter (61.5 vs 74.5 cm) than those planted in adjacent open areas. Vigorous seedlings with average leader increments of 22–23 cm were present on both sites. White spruce foliar nitrogen and sulfur content were not significantly different and were below recommended adequate levels for both sites.

Were there any other differences between sites with a residual aspen canopy and open areas?

Measures of vegetative competition were significantly greater where no aspen residuals were present. Mineralizable nitrogen and exchangeable potassium in the forest floor were greater under aspen residuals. Soil temperatures were slightly lower in the forest floor and higher in the upper mineral soil under aspen residuals, but significant differences could not be tested for. In the open areas, forest floor moisture was greater in May and June but less in July and August of 1989.

Does aspen aid in the establishment of white spruce?

Temperature and moisture amelioration during white spruce germination and seedling establishment are the most likely benefits of aspen canopies in the Fort Nelson area. Long-term benefits from nutrient cycling may also exist.

Does white spruce respond to release from an aspen overstory?

Yes. Thirty-year volume increases ranging from 25 to 304% have been recorded for released white spruce in Saskatchewan and Manitoba. Greatest response seems to occur when white spruce are 15–40 years old. More than one release treatment may be needed if spruce are less than 3 m tall.

More detailed discussion of results and future research needs are given in the body of the report.

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PREFACE

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INTRODUCTION

The relationships between *Picea glauca* (white spruce) and both *Populus tremuloides* (aspen) and *P. balsamifera* (balsam poplar) in the establishment and growth of white spruce have long been a major concern in the management of the boreal forest. Traditionally, only the softwood component of the mixedwood resource has been used, but in recent years greater emphasis has been placed on the hardwood resource.

This research project was initiated in response to management concerns in the Fort Nelson Forest District over the mixedwood relationship between white spruce and two *Populus* species. The specific objectives of the research were:

1. to detail the ecological character of selected mixedwood sites in the Boreal White and Black Spruce Biogeoclimatic Zone (BWBS);
2. to describe patterns of white spruce establishment under a *Populus* canopy in the BWBS;
3. to measure white spruce height and growth increment under hardwood canopies of differing densities in selected BWBS sites;
4. to identify and describe some of the mechanisms by which *Populus* spp. affect the establishment, growth, and development of white spruce in the BWBS;
5. to suggest a manipulation strategy for managing backlog and problem sites for the establishment and optimum growth of planted or naturally regenerated spruce in the BWBS; and
6. to suggest criteria for selecting conifer planting stock for such mixedwood sites.

The project was designed to provide information that would help redefine the silvicultural and timber interpretations currently being applied in the Fort Nelson Forest District.

METHODS

Site Selection and Characterization

Three sites representative of upland aspen - white spruce ecosystems were selected and sampled in 1988. Three additional sites (two upland, one alluvial) were sampled in 1989.

Within each site, three 20 x 20-m replicate plots were established for detailed characterization of soils and vegetation. For each replicate plot, the site and vegetation descriptions were conducted according to the standard procedures used by the B.C. Forest Service (Pojar *et al.* 1987). One modal soil pedon was described and classified according to the procedures established by the Canada Soil Survey Committee (1978).

Soil and Foliar Sampling

Within each 20 x 20-m replicate plot, 15 sampling points were randomly located using a grid system and table of random numbers. At each sampling point the entire forest floor was removed with a knife beneath a 200-cm^2 template. Mineral soil samples were taken with an auger in three depth increments: 0–10 cm, 10–20 cm and 20–40 cm. The soil samples were composited in the field so that one sample from each sampling depth was sent for laboratory analyses. For one replicate plot, all forest floor and 0-10 cm mineral soil samples were analyzed individually to assess variability in soil properties. Three bulk density samples were taken within each replicate plot for each sampling depth.

After air drying, all mineral soil samples were crushed with a wooden roller, passed through a 2-mm sieve to remove the coarse fraction, and stored until chemical analysis was complete. After air drying, all forest floor samples were finely ground and stored until chemical analysis was complete.

On each plot, the current year's foliage from 20 white spruce stems was sampled following the guidelines given by Ballard and Carter (1986). Foliage samples were dried in a microwave oven, finely ground, and stored until chemical analysis was complete. Before grinding, 100 needle weights were determined so that foliar nutrient data could be expressed on a mg/100 needles basis.

Laboratory Analysis

Laboratory methods used for analysis of forest floor and mineral soil samples are given in Table 1. Bulk density of forest floor and mineral soil samples were determined according to the procedures described in Klinka *et al.* 1981. The nutrient status of the sites was characterized on both a concentration (chemical) and area (kg/ha) basis. Foliar samples were analyzed for N, P, K, S, SO_4-S, Ca, Mg, Fe, Al, Mn, Cu, Zn, B and "active" Fe, using the methods recommended by Ballard and Carter (1986).

TABLE 1. Summary of laboratory analyses[a]

Analysis	Method
pH	pH in H_2O (1:1)
Total carbon	Leco induction furnace Bremer and Tabatabai 1971
Total nitrogen	Semi-micro Kjeldahl Black *et al.* 1965
Mineralizable nitrogen	Anaerobic incubation Powers 1980
Exchangeable potassium Exchangeable calcium Exchangeable magnesium	Ammonium acetate extraction Heald 1965; and atomic absorption spectrophotometry Price 1978
Extractable phosphorus	Bray P-1 extraction Bray and Kurtz 1945
Extractable sulfate sulfur	Calcium chloride extraction Tabatabai and Bremner 1970

[a] Abbreviations used in the text are as follows:

Analysis	Abbreviation in text
pH	pH
Total carbon	TC
Total nitrogen	TN
Mineralizable nitrogen	minN
Exchangeable potassium	exK
Exchangeable calcium	exCa
Exchangeable magnesium	exMg
Extractable phosphorus	etP
Extractable sulfate sulfur	SO_4-S

Soil Moisture and Temperature

Three aluminum neutron-probe access tubes were installed on each replicate plot, and two additional tubes were installed on each of three sites. The additional tubes were excavated during the sampling season to correlate the neutron-probe readings with gravimetric sampling of mineral soil. Forest floor moisture status was monitored with three gravimetric samples from each plot during each moisture sampling visit. A 15-cm diameter PVC tube was used to assess precipitation inputs at each site during the growing season.

Correlations between mineral soil gravimetric samples and neutron probe readings were found to be inconsistent. Further tests on the neutron probe suggested that results were not reliable for measuring soil water content (M. Osberg, pers. comm., 1990, B.C. Ministry of Forests). As a result, soil moisture data for 1989 were not analyzed.

Thermistors to monitor soil and air temperatures were installed on one replicate plot for each site. Sampling locations were at 1 cm below the forest floor surface, at the forest floor/mineral soil interface, and at mineral soil depths of 5, 10, 20 and 50 cm. One thermistor was placed 1 m above the ground surface to monitor air temperature. Measurements were made with thermistors every 5 minutes; daily means, minima

and maxima were recorded on a Campbell Scientific datalogger (CR 10). Growing-season data for all sites and all sampling locations were not obtained over the entire 1989 season because bears and hares disturbed the monitoring equipment.

Soil temperature analyses were based on temperature degree-day summations of mean daily temperature. The soil degree-day accumulations were calculated for all monitored depths in the soil profile, with 0°C as the base, for the May 15 to September 15 period. The 0°C base was chosen so that comparisons could be made with studies done in Alaska (Viereck *et al.* 1983).

Vegetation Sampling

Single tree vegetation subplots

Measurements were based on a 1.26-m radius (5 m^2) tree-centred subplot. For each competing species with more than 5% cover and greater than one-half the height of the seedling within the subplot, three measures were taken: 1) percentage cover within the subplot; 2) mean height of the competing vegetation; and 3) distance between Competing vegetation and the white spruce seedling. The methodology described above has been used in the Prince George Forest Region for white spruce plantations (C. DeLong, pers. comm., 1988, B.C. Ministry of Forests).

In addition, the following measurements were taken for each seedling: total height, leader increment height for the past three seasons, maximum "crown" diameter, root collar diameter, and number of buds on the terminal leader.

Stand structure

Age and height of six dominant or co-dominant aspen, plus diameter at 1.3 m and number of aspen stems within each replicate plot, were determined. Similar measurements were made for understory white spruce. These were used to calculate basal area, stocking, and site index.

Rooting characteristics

In the 1988 sampling season, in one soil pit per replicate plot, the root density and depth patterns of aspen and white spruce were determined with the use of a grid system on the face of a soil pit (Strong and LaRoi 1983).

Canopy light characteristics

Light quantity for individual seedling subplots was determined with an integrating light sensor (Decagon Sunfleck Ceptometer). Sampling for fractional interception followed the sampling design described in the Decagon device's User's Manual. Sampling was originally to be done during the growing season (May 15–September 15) on at least nine occasions, for the early morning, midday, and late afternoon periods. On only one occasion (July 12,1989) could all trees be sampled under similar light conditions.

Data Analysis

Data were analyzed with SYSTAT and SYGRAPH (Wilkinson 1988a, 1988b).

DESCRIPTION OF STUDY SITES

Six sites were sampled in this study. Five represented upland aspen-white spruce ecosystems, and one represented early successional stages of an alluvial (balsam poplar) ecosystem. Sites 1 and 2 were located near Mile 323 of the Alaska Highway; Site 3 was located near Mile 308 of the Alaska Highway; Site 4 was 26 km north of the Alaska Highway on the Fort Simpson Trail (317 Road); Site 5 was approximately 3 km northwest of Prophet River along the old Alaska Highway; and Site 6 was near Kledo Creek on the floodplain of the Muskwa River, approximately 45 km west of Fort Nelson. Selected environmental features are summarized in Table 2.

TABLE 2. Selected characteristics of study plots

Site	Plot	Forest floor depth (cm)	Soil type	Rooting depth, mineral soil (cm)	Texture, upper mineral soil	Aspect (°)	Slope (%)
1	1	7.3	O.GL[a]	70	SiCL	140	1
	2	8.8	O.GL	70	CL	140	2
	3	7.6	O.GL	70	CL	140	2
2	1	8.5	G.GL	70	SiC	140	1
	2	8.4	O.GL	75	L	140	1
	3	8.8	G.GL	70	CL	140	1
3	1	9.0	O.GL	70	CL	180	11
	2	8.8	O.GL	70	CL	180	8
	3	12.0	O.GL	70	L	180	15
4	1	5.0	O.GL	80	SiL	10	2
	2	5.1	O.GL	65	SiCL	10	2
	3	5.5	O.GL	65	SiL	10	2
5	1	4.8	E.DYB	90+	LS	30	2
	2	4.9	E.DYB	90+	S	30	2
	3	4.2	E.DYB	90+	SL	30	2
6	1	2.3	CU.R	100+	SL	—	0
	2	3.0	CU.R	100+	SL	—	0
	3	2.6	CU.R	100+	SiL	—	0

[a] O.GL = Orthic Grey Luvisol, G.GL = Gleyed Grey Luvisol, E.DYB = Eluviated Dystric Brunisol, CU.R = Cumulic Regosol

Sites 1 and 2

Sites 1 and 2 were in a former aspen-spruce stand, harvested for spruce in the fall of 1983. The aspen residuals were approximately 120 years old with a Site Index (SI) of 28 m/100 years. With no site preparation, white spruce PBR 313 and PSB 313 stock was planted in 1984. Site 1 represents areas with residual aspen; Site 2 represents open areas.

Residual aspen on the replicate plots of Site 1 ranged from 175 to 450 stems per hectare, and residual white spruce from 100 to 650 stems per hectare (Table 3). The majority of residual white spruce was less than 3 m tall. Total shrub cover ranged from 28 to 45%. The shrub layers were dominated by regenerating aspen (4–12% cover), *Viburnum edule*, *Shepherdia canadensis*, and *Rosa acicularis*. Total herb cover ranged from 28 to 44%. Common herbs were *Rubus pubescens*, *Cornus canadensis*, *Calamagrostis canadensis*, and *Petasites palmatus*. *Hylocomium splendens* dominated the moss layer (14–33% cover).

Residual aspen on the replicate plots of Site 2 ranged from 0 to 75 stems per hectare (Table 3). One replicate plot had residual spruce at 75 stems per hectare. Total shrub cover ranged from 30 to 52%. Species present in the shrub layer were the same as for Site 1, but percent cover of aspen regeneration was greater on Site 2 (ranging from 8 to 25% cover). Common herbs were *Epilobium angustifolium, Rubus pubescens, Cornus canadensis, Elymus innovatus,* and *Mitella nuda* (total herb cover 44–68%). *Hylocomium splendens* dominated the moss layer (2–5% cover).

TABLE 3a. Selected stand structure data for Sites 1 and 2[a]

Site	Plot	At stems/ha	At regen. stems/ha	Sw regen. stems/ha	Sw planted stems/ha	Sw residual stems/ha	At SI m/100 yr
1	1	450	5 025	2 075	975	650	27.5
	2	325	9 675	5 075	1 125	125	27.1
	3	175	9 225	6 400	1 400	100	31.0
2	1	50	10 775	2 875	1 300	75	—
	2	25	12 325	7 075	1 275	0	—
	3	0	15 075	23 325	1 050	0	—

TABLE 3b. Selected stand structure data for Sites 3, 4 and 5

Site	Plot	At stems/ha	Sw stems/ha	Sw potential crop tree stems/ha	At SI m/100 yr	Sw SI m/100 yr
3	1	750	3 350	1 200	24.5	20.4
	2	700	2 950	1 325	26.7	16.5
	3	600	3 300	1 750	25.5	15.4
4	1	950	1 575	1 200	29.9	12.6
	2	800	1 500	1 150	31.0	11.7
	3	825	1 000	1 000	31.8	11.8
5	1	4 275	1 175	750	26.6	20.4
	2	2 900	1 450	1 150	29.7	15.4
	3	2 950	1 350	1 100	25.4	23.2

TABLE 3c. Selected stand structure data for Site 6

Site	Plot	Ac stems/ha	Alder stems/ha	Sw stems/ha	Sw > 100 cm stems/ha
6	1	12 600	3 600	33 950	2 975
	2	10 650	5 200	25 625	1 750
	3	9 450	1 775	22 850	3 900

[a] At = aspen, Ac = balsam poplar, Sw = white spruce, SI = site index.

The soils were Orthic Grey Luvisols (Sikanni series, Valentine 1971) derived from calcareous, moderately fine-textured morainal materials. Textures ranged from clay loam to clay, with coarse fragment content less than 5%. Drainage was imperfect and mottles were usually present in the clay-textured Bt horizon. Differences between replicate plots were small, but some were classified as Orthic Grey Luvisols and others as Gleyed Grey Luvisols. Forest floors were Hemihumimors (Klinka *et al.* 1981), averaging 7–9 cm in depth.

Numbers of natural aspen and white spruce regeneration versus numbers of aspen residuals are given in Figure 1. The expected trend of greater aspen regeneration with fewer aspen residuals was present. The exceptional numbers of white spruce seedlings on one replicate plot were due to very successful establishment of young seedlings on favorable microsites (those with mineral soil exposed from windthrown aspen and logging disturbances).

Sites 1 and 2 were classified as the Aspen-White Spruce Association (Annas *et al.* 1984) of the BWBSa1. Soil moisture regimes were mesic-subhygric.

Site 3

The aspen overstory of Site 3 had approximately 700 stems per hectare, age 115 years, with an SI of 26 m/100 years (Table 3). White spruce was present as an understory of varying ages and heights. Total number of white spruce stems was approximately 3000 stems per hectare. The number of white spruce "potential crop trees" ranged from 1200 to 1700 per hectare; average height of the trees was 10–15 m. Maximum age of white spruce was 55 years. Stand origin was due to fire.

The large numbers of white spruce in the shrub layers resulted in total shrub cover estimates of 50–60%. Other shrubs present were *Rosa acicularis* and *Viburnum edule*. Herb cover was low (8–11%), probably due to shading by the white spruce. Common herbs were *Cornus canadensis*, *Rubus pubescens*, and *Aralia nudicaulis*. *Hylocomium splendens* dominated the moss layer (10–20% cover).

The soils were Orthic Grey Luvisols (Fort Nelson series, Valentine 1971) derived from calcareous silty clay parent materials. Forest floors were Hemihumimors (Klinka *et al.* 1981), averaging 10 cm in depth.

Site 3 was classified as the Aspen-White Spruce Association (Annas *et al.* 1984) of the BWBSa1. Soil moisture regime was mesic.

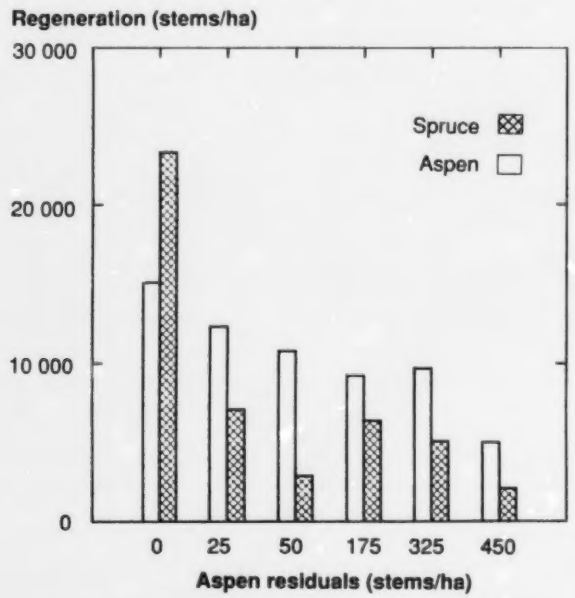

FIGURE 1. Natural regeneration of white spruce and aspen under aspen residuals on Sites 1 and 2.

Site 4

The aspen overstory of Site 4 had 800–950 stems per hectare, age 85 years, with an average SI of 31 m/100 years (Table 3). White spruce was present as an understory of varying ages and heights. Total numbers of white spruce ranged from 1000 to 1575 stems per hectare. The number of white spruce "potential crop trees" ranged from 1000 to 1200 stems per hectare; average height of the trees was 4–10 m. Maximum age of white spruce was 63 years. Stand origin had been from fire, possibly in combination with windthrow. Sources of microtopography included decaying wood in the forest floor and mineral soil hummocks.

Total cover of shrubs ranged from 40 to 70%. *Alnus incana, Viburnum edule,* and *Rosa acicularis* were the most common shrubs. Herb cover was 38–45%. Common herbs were *Rubus pubescens, Cornus canadensis, Petasites palmatus,* and *Lycopodium clavatum. Hylocomium splendens* dominated the moss layer (5–35% cover).

The soils were Orthic Grey Luvisols (Sikanni series, Valentine 1971; Kowall 1982). Soil profile development was relatively shallow. A dense clay-textured Bt horizon was present at 20 cm, and the massive clay-textured parent material restricted drainage and rooting depth. Forest floors were Hemihumimors (Klinka *et al.* 1981), averaging 5 cm in depth.

Site 4 was classified as the Aspen-White Spruce Association (Annas *et al.* 1984) of the BWBSa1. Soil moisture regime was mesic.

Site 5

The aspen overstory of Site 5 had 2900–4275 stems per hectare, with an average age of 45 years and an SI of 27 m/100 years (Table 3). The white spruce understory varied in age and height. Total white spruce stems per hectare ranged from 1175 to 1450. Numbers of "potential crop trees" were 750 to 1150 stems per hectare; average height of the trees was 4–8 m. Maximum age of white spruce was 45 years; common ages of the trees were 36, 31 and 26 years. Stand origin had been from fire. Waves of white spruce establishment in the understory probably coincided with combinations of good seed years and favorable growing conditions. Similar "wave establishment" of white spruce was observed on Sites 3 and 4.

Rosa acicularis and *Shepherdia canadensis* dominated the shrub layer, which had 37–50% cover. Herb layer cover ranged from 35 to 70%, dominated by *Epilobium angustifolium, Elymus glauca, Cornus canadensis, Pyrola asarifolia,* and *Linnaea borealis.* Moss cover (*Hylocomium splendens*) was very low (0–3%).

The soils were Eluviated Dystric Brunisols, most similar to the Bar series (Valentine 1971), derived from sandy loam glaciofluvial materials. Gravelly layers were common. Forest floors were Hemihumimors (Klinka *et al.* 1981), averaging 5 cm in depth.

Site 5 was most similar to the Aspen-White Spruce Association (Annas *et al.* 1984) of the BWBSa1. Soil moisture regime was submesic. Well-drained coarse-textured soils with an aspen-white spruce forest is an unusual combination in the Fort Nelson Forest District.

Site 6

Site 6 underwent surface disturbance during logging activities, probably in the 1960's. Flooding events had occurred since logging, most recently in 1983. Alluvial sites with the combination of white spruce regeneration and good access from Fort Nelson were very difficult to find during site selection. In spite of the disturbance, Site 6 was the best available alluvial site to monitor and compare with upland sites.

Numbers of balsam poplar ranged from 9400 to 12 600 stems per hectare (Table 3). Most balsam poplar were less than 20 years old. Alder (*Alnus incana*) ranged from 1700 to 5200 stems per hectare. Total numbers of white spruce were between 22 800 and 34 000 stems per hectare. The white spruce greater than 1 m in height were 1750–3900 stems per hectare.

Shrub cover ranged from 72 to 94%, dominated by balsam poplar, alder and white spruce. Other shrubs present with low (< 10%) cover were *Shepherdia canadensis, Cornus sericea, and Ribes triste*. Herb cover was low (10–20%). The most common herbs were *Mertensia paniculata, Epilobium angustifolium,* and *Equisetum pratense*. Moss cover had not yet developed in this early successional ecosystem.

The soils were Cumulic Regosols (Snake series, Valentine 1971), consisting of layers of fine sands, sandy loams and occasionally silt loams. Forest floors were Hemimors (Klinka *et al.* 1981) averaging 2.5 cm in depth.

Site 6 was classified as the Balsam Poplar – Horsetail Association (Annas *et al.* 1984). Soil moisture regime was mesic–subhygric.

COMPARISON OF STUDY SITES

Soil Temperatures 1989

Comparisons of degree days (Fig. 2) between sites show that Site 3 had the lowest accumulation of degree days (0°C base) at all depths in the soil profile. This was probably the result of the dense canopy of white spruce regeneration intercepting radiation, the thick forest floor (9–12 cm, Table 2) providing insulation, and the fine-textured mineral soil having a lower thermal conductivity than coarser-textured soils. Site 6 had the greatest number of degree days at the 10 and 50 cm depths. The contributing factors would include the relatively thin forest floor (2–3 cm), greater thermal conductivity of a coarser-textured soil, and the warmer microclimate typical of alluvial sites along the major river systems (Valentine 1971). Site 5 had slightly fewer degree days than did Sites 2 and 4 with their fine-textured soils, at the 10 cm mineral depth. However, at the 50 cm depth, Site 5 had more degree days than Sites 2 and 4. The greater number of degree days at 50 cm for the coarser-textured soils of Sites 5 and 6 implies greater available rooting volume which is not limited by temperature.

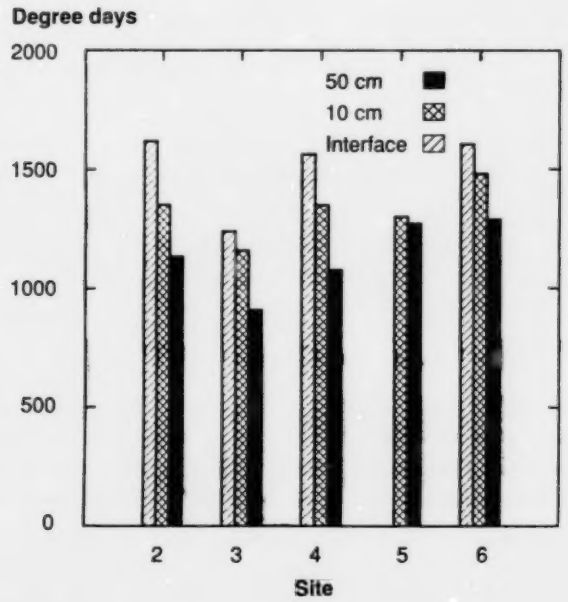

FIGURE 2. Degree days (0°C base) at the forest floor-mineral soil interface, 10 cm and 50 cm mineral soil depths during 1989.

Productive white spruce, aspen and balsam poplar forests in Alaska (Viereck *et al.* 1983) had 798–1140 degree days (0°C base) at a 10 cm depth below the moss layer. These were slightly lower than the degree-day values for 1989 at similar depths on the Fort Nelson study sites.

While Site 6 had greater soil degree days than the upland sites (Fig. 2), the seasonal temperature pattern was unique (Fig. 3). Site 6 soil temperatures at 10 cm were consistently warmer than those on the upland sites until mid-August (Julian Day 225; Fig. 3). Soil temperatures declined after mid-August, and by late September (Julian Day 250; Fig. 3) they were below the daily mean soil temperatures found on upland sites.

Valentine (1971) noted that, because of topography, valley bottoms in the Fort Nelson area are liable to advection frosts at all times of the year. The valley bottoms actually have a shorter frost-free season than the uplands (Valentine 1971). Low cloud and fog were observed to linger in valleys for several hours after upland sites were in sunshine during late August and September 1989. Within the shorter frost-free season, alluvial sites appear to have a warmer microclimate with warmer soil temperatures (Fig. 3). These results are consistent with the greater productivity of alluvial ecosystems, and further emphasize important environmental differences between upland and alluvial sites.

Soil Moisture

Forest floor moisture contents for Sites 3, 4, 5 and 6 have unique patterns (Fig. 4). Time between sampling and the most recent rainfall event probably account for much of the variability. Precipitation inputs varied dramatically between the sites (Fig. 5) and reflect the variability that can result from intense local showers (Site 5, Fig. 5).

As described above in "Methods," the neutron-probe readings were not acceptable as absolute values of volumetric water content of the mineral soils. In a general way, comparisons between sites and seasonal trends could be observed. The fine-textured soils (Sites 3, 4) had greater water content than the coarser-

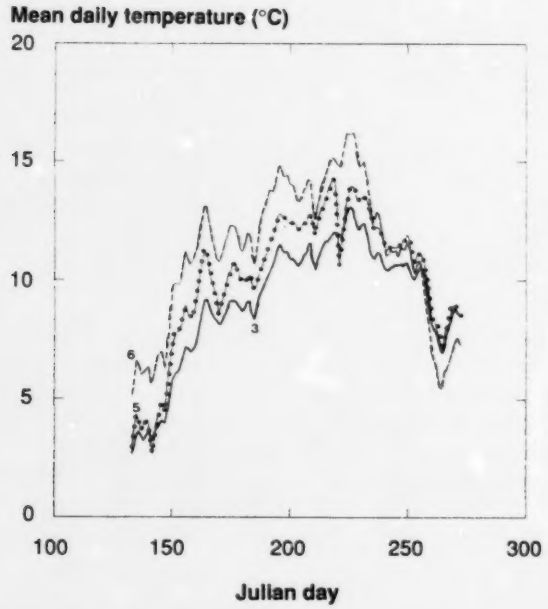

FIGURE 3. Mean daily temperature at 10 cm depth in mineral soil for Sites 3, 5 and 6 during 1989.

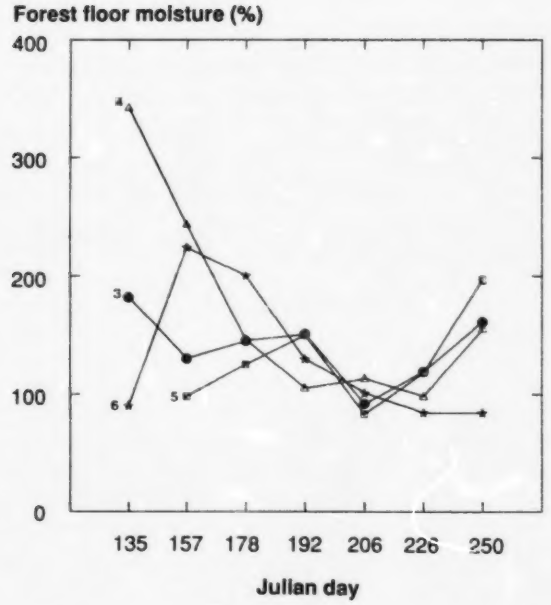

FIGURE 4. Forest floor moisture content during 1989 for Sites 3, 4, 5 and 6.

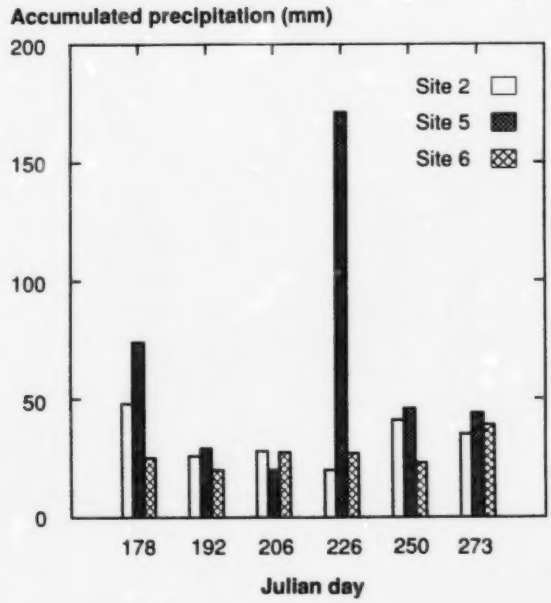

FIGURE 5. Accumulated precipitation for Sites 2, 5 and 6 during 1989.

textured soils (Sites 5, 6) at all times during the growing season (data not shown). On all sites, mineral soil water content declined from a high in early June to a low in mid-August in 1989. Monitoring soil moisture over several years, as well as determining available water storage capacity, would provide better characterizations of plant-available water for each site.

Soil Nutrient Status

The soil nutrient results are similar to those reported from other studies in the Fort Nelson area (Valentine 1971; B.C. Ministry of Forests, unpublished data) and from similar ecosystems in Alaska (Van Cleve *et al.* 1983).

Sites 1, 2, 3 and 6 had the greatest amounts of total N (Fig. 6) in the soil profile sampled (forest floor plus upper 40 cm mineral soil). Site 5 had significantly less total N than any other site (Fig. 6). Relationships between the sites changed dramatically when minN (an index of available N) quantities were compared (Fig. 7). Quantities of minN were not significantly different (Student-Newman-Keuls range test, 0.05 level) between Sites 2, 3 and 5. These results suggest that N availability between the sites does not vary as much as total N quantities. The low minN values for Site 6 were unexpected considering that total N quantities were relatively high, and large numbers of alder would be expected to be fixing N on the site.

Interactions between soil temperature, soil moisture, and quality of organic matter may account for the relatively good mineralizable N status of Site 5, which appeared to have low inherent fertility (because of its coarse-textured soils). Forest floor nutrients of 40- to 50-year-old aspen stands in Minnesota were recycled more rapidly on a relatively nutrient-poor sandy soil than on a loam (Perala and Alban 1982). The rapid cycling was believed to compensate for the lower inherent fertility of the sandy soil. Causes of the relatively rapid turnover were unknown (Perala and Alban 1982). Forest floor chemistry (organic matter quality) interacting with soil temperature was identified as the major control of productivity and nutrient cycling in Alaskan forest ecosystems (Van Cleve *et al.* 1983). Within a forest type (e.g., aspen), moisture status was hypothesized as being secondary to temperature but greater than nutrient status in determining productivity (Van Cleve and Yarie 1986).

Site 3 had the greatest quantities of SO_4-S (Table 4), which is the form of S available to trees (Ballard and Carter 1986). The principal reservoir of S in soils is organic matter, although some rocks and parent materials contain forms of S which can be released as SO_4-S through weathering (Ballard and Carter 1986). Moisture status, residence time of soil inputs, and hydrologic pathways were identified as important factors for determining release of SO_4-S in some Ontario forest soils (Neary *et al.* 1987).

Site 6 had the greatest exCa (exchangeable calcium) quantities (Table 4) and highest pH, which is common for alluvial ecosystems near Fort Nelson (Valentine 1971) and in other boreal forest areas such as Alaska (Van Cleve and Yarie 1986). Site 5 had the lowest quantities of exCa and exMg (exchangeable magnesium) (Table 4), which is consistent with parent material of a glaciofluvial origin. In general, soils of alluvial (Site 6) and glaciofluvial (Site 5) origin are most likely to have lower Mg and K levels than soil of glacial till origin (Sites 1, 2, 3 and 4) (Leaf 1968).

A number of interactions are summarized in Figure 8, including mineralizable N in the forest floor in relation to moisture content of the forest floor and soil temperature 5 cm below the forest floor for the study sites. Site 3 has accumulated a relatively thick forest floor. This contributes to its cooler soil environment and represents an accumulation of N. Site 6 is clearly in contrast with its young successional ecosystem, thin forest floor, and warmer microclimate. Comparisons between sites are limited with the existing data. Indices of plant-available moisture and soil temperatures monitored over longer time periods are needed to better characterize environmental conditions for these sites.

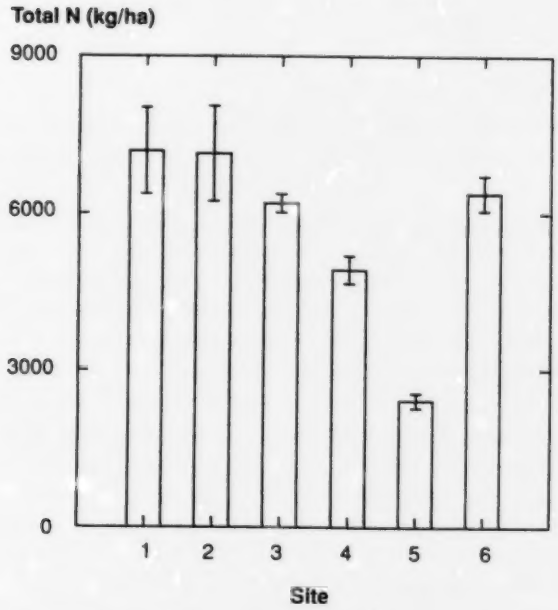

FIGURE 6. Total nitrogen content for forest floor plus mineral soil (0–40 cm).

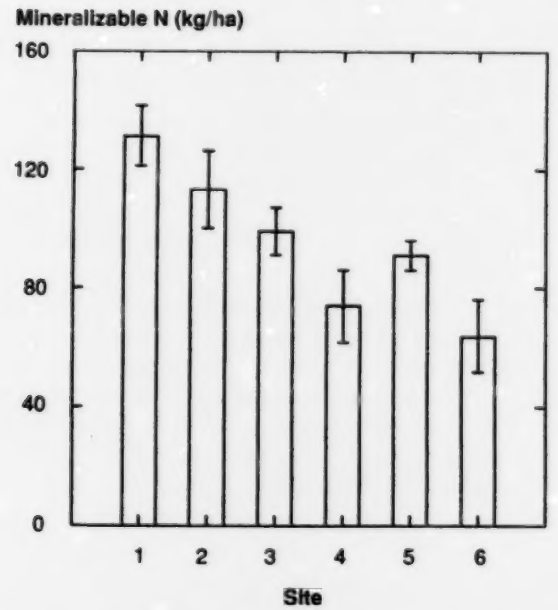

FIGURE 7. Mineralizable nitrogen content for forest floor plus mineral soil (0–40 cm).

TABLE 4. The results of Student-Newman-Keuls range test[a] for SO_4-S, exCa, and exMg forest floor, plus mineral soil quantities for each site (n=3)

Property (kg/ha)	Site					
SO_4-S	3	2	1	4	5	6
	21.0	15.0	14.9	10.4	10.3	9.7
exCa	6	1	2	3	4	5
	11 858	10 134	9 590	8 765	6 580	3 348
exMg	1	2	3	4	6	5
	2 889	2 862	1 914	1 581	751	289

[a] Underlined values are not significantly different at the .05 level.

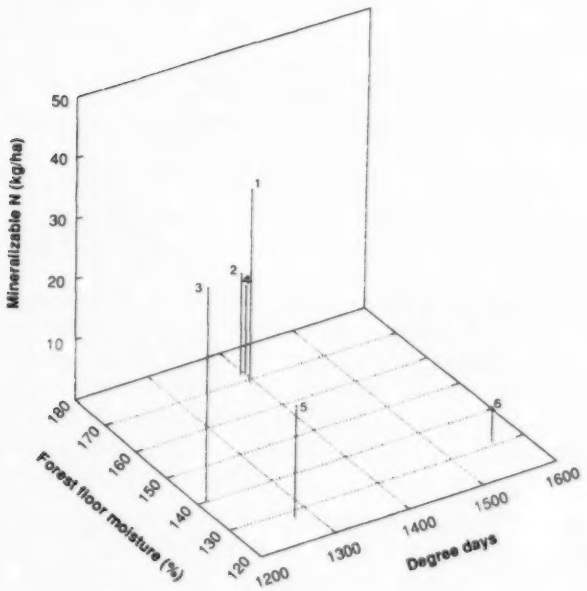

FIGURE 8. Forest floor mineralizable nitrogen in relation to average forest floor moisture content and degree days (0°C base) at 5 cm depth of mineral soil.

Foliar Nutrient Analysis

All sites were below recommended adequate levels (Ballard and Carter 1986) for N and S (Table 5). Fifteen of the 18 replicate plots had below the recommended adequate levels for Mg. However, the four replicate plots with the lowest foliar Mg level were rated as having only a slight to moderate deficiency. Two replicate plots were below recommended adequate levels for Cu. Foliar Fe levels were ranked in relatively low supply for Sites 3, 4, 5 and 6, but were not in the deficient range.

TABLE 5. Summary of foliar nutrient analysis results

Site	Plot	Foliar nutrient[a] (% deviation from adequacy)				
		N	Mg	S	Cu	B
1	1	-23***	-17	-48**	15	-9*
	2	-19***	-17	-43*	-24**	8*
	3	-25***	-17	-49**	15	-25***
2	1	-25***	-9	-46*	53	-9*
	2	-26***	-25**	-49**	15	-9*
	3	-27***	-17	-45*	92	-25***
3	1	-29***	8	-45*	15	75
	2	-34***	0	-45*	15	91
	3	-34***	0	-42*	15	66
4	1	-34***	-9	-49**	15	50*
	2	-34***	-9	-44*	92	58*
	3	-34***	-9	-51**	53	58*
5	1	-24***	-17	-38*	15	58*
	2	-30***	-17	-45*	15	33*
	3	-30***	-17	-44*	15	75
6	1	-37***	-25**	-49**	-24**	41*
	2	-24***	-25**	-47**	15	58*
	3	-34***	-25**	-54**	53	50*

[a] * No deficiency, but N-induced deficiency possible.
** Deficiency likely, N-aggravated deficiency possible.
*** Deficiency likely.

The results were similar to those of Ballard (1984) who conducted a broad survey of nutritional problems in planted white spruce in the Prince George and Cariboo Forest Regions. The results of Ballard (1984) indicated that N, Mg, Fe, and Cu often appeared to be seriously deficient in young, planted white spruce, and that S would often become growth-limiting if the N deficiency were relieved. Both the frequency and severity of N, Fe, and Cu deficiencies appeared to be greater where burning or mechanical site preparation had been carried out (Ballard and Hawkes 1989). No site preparation or prescribed burning had been carried out on the Fort Nelson sites. Foliar Fe and Cu levels were adequate, with the exception of Cu on two replicate plots.

The below-recommended foliar B levels should not be considered as strong evidence of B deficiency. Boron is not readily translocated from older foliage to the current year's foliage (Mengel and Kirkby 1982). Movement of soil B to plant roots is by mass flow with soil moisture. As a result, foliar B levels may fluctuate annually depending on soil moisture levels during the growing season (Mengel and Kirkby 1982).

Foliar N concentrations were greatest for Sites 1 and 2 (Table 6). The planted seedlings on these sites had significantly greater foliar N than the naturally established, older white spruce on the other sites. The greater foliar N concentrations of white spruce seedlings on Sites 1 and 2 may be partially due to the smaller foliar biomass and needle size of these seedlings (Table 7).

When foliar nutrient data were expressed on a mg/100 needles basis, the sites were arranged in a different pattern (Table 7). Site 5, on the driest, relatively nutrient-poor site, had the largest needles and greatest amount of N per weight of foliage. When foliar nutrients (mg/100 needles) for Site 5 were compared to those for Sites 3 and 4 (Table 7) which had similar stand structure and age class, Site 5 appeared to have the best nutrient status. This pattern was consistent for most nutrients (e.g., S, Table 7), although differences were not necessarily significant. Stand history (such as suppression of the white spruce), internal nutrient cycling,

weather patterns of recent years, and the inherent fertility of the site are all factors influencing foliar nutrient status. The significantly greater foliar N content of Site 5 (Table 7) is in contrast to soil measures of total N and minN (Figs. 6 and 7).

TABLE 6. The results of Student-Newman-Keuls range test[a] for foliar N and SO_4-S concentrations for each site (n=3)

Property	Site					
	1	2	6	3	5	4
Foliar N (%)	1.21	1.15	1.07	1.06	1.03	1.03
	3	4	5	6	1	2
SO_4-S (ppm)	134	109	89	74	66	43

[a] Underlined values are not significantly different at the .05 level.

TABLE 7. The results of Student-Newman-Keuls range test[a] for 100 needle weight, and foliar N, S and SO_4-S expressed as mg/100 needles for each site (n=3)

Property	Site					
	5	4	3	6	2	1
100 needle weight (mg)	547	463	445	392	246	236
N (mg/100 needles)	613	477	471	418	284	286
S (mg/100 needles)	50	39	40	32	21	20
	3	4	5	6	1	2
SO_4-S (mg/100 needles)	5.97	5.05	4.85	2.90	1.55	1.05

[a] Underlined values are not significantly different at the .05 level.

Rooting Characteristics

In one soil pit per replicate plot for Sites 1, 2 and 3, the density and depth of roots were recorded. Only large (> 0.5 cm diameter) roots of aspen and white spruce could be distinguished in the field. Total rooting depths varied from approximately 75 cm on fine-textured soils to over 100 cm on the alluvial site (Table 2).

The greatest concentration of roots was at the organic-mineral soil interface (Figure 9). Spruce roots were common in the lower portions of the forest floor; large aspen roots were more common than white spruce roots at depths of 20 cm or more below the organic-mineral soil interface.

These results were very similar to those of Strong and LaRoi (1985) for aspen sites on clay loam till in Alberta. The predominance of white spruce roots in the forest floor above aspen roots, appears to be a competitive advantage for white spruce.

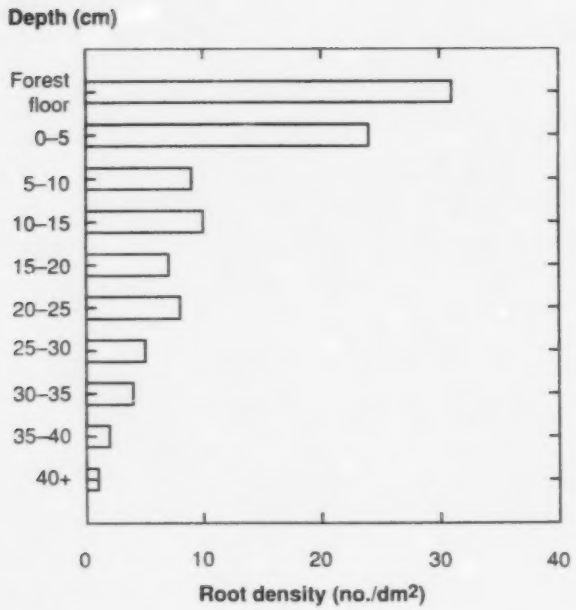

FIGURE 9. Root density distribution for Site 3.

SPRUCE SEEDLING RESPONSE TO A RESIDUAL ASPEN CANOPY

The Mile 323 Plantation (Sites 1 and 2) offered a research opportunity to compare environmental conditions and white spruce seedling performance for contrasting cover of aspen residuals.

Microclimate

Frost hazard between Sites 1 and 2 may have differed significantly. For comparable dates, Site 2 had more potential frost events (air temperature < 0°C at 100 cm) of greater severity than Site 1 (Figs. 10 and 11). The low minimum temperatures of Julian day 185 (July 4) on Site 2 (Fig. 11) is an example of a potential frost event in the middle of the growing season. Comparable measurements for that date are unavailable for Site 1 because a bear disconnected thermistors from the datalogger. However, no evidence of frost damage was observed during 1989 on any white spruce seedling at either site. Except for particular microsites, frost damage to planted white spruce seedlings has not been common in the Fort Nelson area (J. Revel, pers. comm., 1990, B.C. Ministry of Forests).

As described by Stathers (1989), vegetation can have either a beneficial or detrimental effect on the occurrence of frost, depending on its height, structure, and density. A tall closed canopy (Site 1) reduces the frost hazard by reducing the net radiative loss from the ground surface. Short canopies (Site 2) are not as effective as taller canopies that have higher foliage temperatures and that block more of the seedlings view of the cold sky (Stathers 1989).

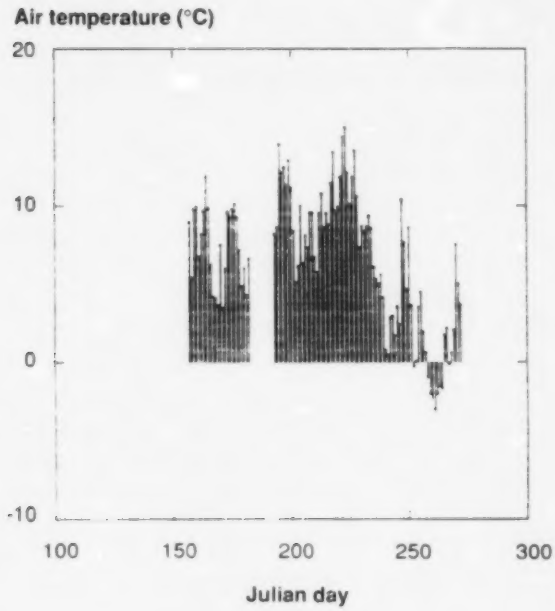

FIGURE 10. Site 1 minimum air temperatures in 1989.

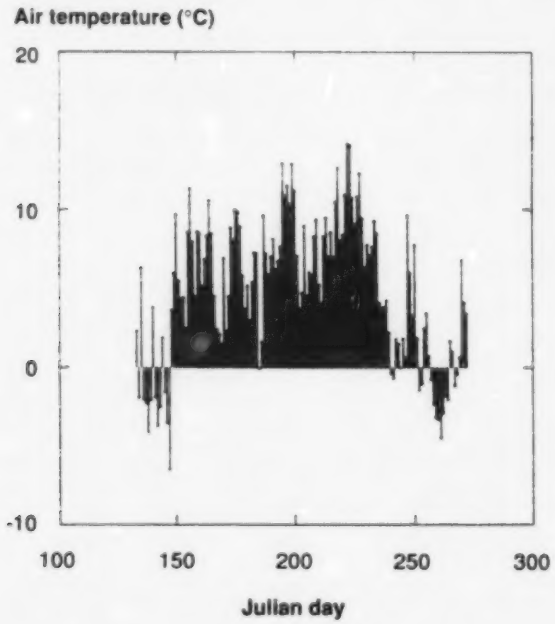

FIGURE 11. Site 2 minimum air temperatures in 1989.

Soil Properties

Disturbance by animals prevented soil temperature comparisons over the entire growing season between Site 1 and Site 2. For the periods when both sites were monitored between May 15 and September 15, Site 2 had slightly more degree days in the forest floor and similar degree days in the mineral soil (Fig. 12). No statistical analysis could be done since temperature measurements were not replicated. The differences observed between the sites may have been due to variability in soil properties.

Clearcutting of floodplain white spruce sites in Alaska (Dyrness *et al.* 1988) resulted in significant increases in soil temperature (29% increase at 10 cm depth) compared to that in undisturbed controls. Year-to-year variations in soil temperatures were relatively large in the Alaska study. Differences in soil temperature were apparent in the second and third summers after logging, but not in the first (Dyrness *et al.* 1988). Many of the soils were on the verge of developing permafrost, which may account for the dramatic temperature responses to some site treatments described by Dyrness *et al.* (1988).

We can only speculate about temperature differences which may have occurred between logging in 1983 and the beginning of monitoring in 1989. The rapid re-establishment of an aspen canopy and the relatively thick, undisturbed forest floor would both contribute to the relatively slight differences in soil temperatures between Sites 1 and 2 in 1989.

Forest floor moisture trends over the growing season indicated that Site 2 may have had greater moisture content in May and June (Julian Day 120–180), and less moisture for the remainder of the growing season (Fig. 13). The degree of sampling conducted was insufficient for adequately describing forest floor moisture fluctuations over the season. More intensive sampling of moisture inputs and outputs would be needed to quantify differences in moisture regime between the two sites and its implications for nutrient cycling and productivity.

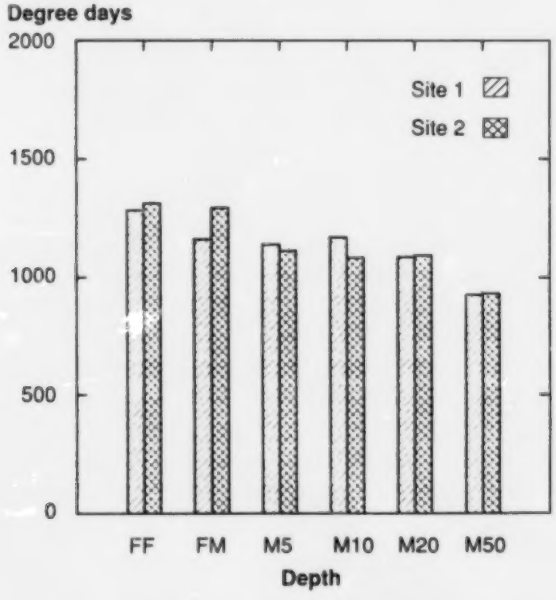

FIGURE 12. Degree days (0°C base) for Sites 1 and 2 when dataloggers were operating on both sites during 1989 (FF = forest floor; FM = forest floor-mineral soil interface; M5 = 5 cm depth mineral soil; M10 = 10 cm depth mineral soil; M20 = 20 cm depth mineral soil; M50 = 50 cm depth mineral soil).

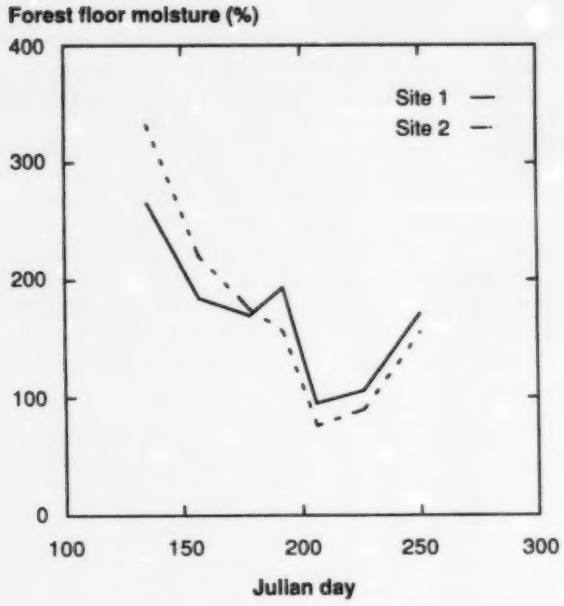

FIGURE 13. Forest floor moisture content for Sites 1 and 2 during 1989.

Mineral soil moisture differences between Sites 1 and 2 could not be assessed quantitatively because of difficulties in calibrating the neutron probe to gravimetric moisture samples. Differences between the two sites were small, however, when neutron-probe counts were compared. Continued measurements on Site 2 would allow monitoring of moisture status during successional changes.

The pH of the upper strata (0–10 cm) was the only mineral soil chemical property to differ significantly between Sites 1 and 2 (Table 8). However, the amount of difference between the two sites (0.2 pH units) was unlikely to influence nutrient availability or the plant rooting environment strongly.

Forest floor minN and exK (exchangeable potassium) were both greater under the residual aspen of Site 1 (Table 8). This result was consistent on both a chemical concentration and area (kg/ha) basis. Depth and bulk density of forest floors did not vary significantly between the two sites.

TABLE 8. Mean and standard deviation (in brackets) of selected soil properties for Sites 1 (residual aspen present) and 2 (no residual aspen) (n=3)[1]

Site	Mineral soil (0–10 cm)	Forest floor			
	pH	minN (kg/ha)	exK (kg/ha)	Depth (cm)	Bulk density (g/cm^3)
1	5.3a	32.2a	58.0a	7.9a	0.078a
	(0.1)	(11.3)	(20.8)	(0.8)	(0.014)
2	5.1b	17.0b	36.7b	8.6a	0.068a
	(0.1)	(4.6)	(5.5)	(0.2)	(0.006)

[1] Values followed by the same letter do not differ significantly (Mann-Whitney U Test, p = 0.05).

Assuming that the pre-harvest conditions were the same on the two sites, the greater nutrient uptake by the aspen regeneration on Site 2 may account for the differences. Not only were there greater numbers of aspen stems on Site 2 (Fig. 1), but aspen regeneration on the site was larger and more vigorous. Compared to that in an uncut control, 4-year-old aspen regeneration had a greater uptake of N and K in an Ontario mixed hardwood forest (Hendrickson 1988). Within 2 years following fire, aspen stands originating from root suckers may produce nearly 30% of the annual above-ground biomass production encountered in a mature 60-year-old stand of aspen (Dyrness *et al.* 1986). Nutrient uptake from the environment would have greater importance than internal nutrient cycling for such young stands.

The lack of differences in forest floor depth and bulk density suggest that forest floor decomposition was not greatly enhanced by increased solar radiation after removal of the tree canopy on Site 2. As previously discussed, soil temperature differences in 1989 did not appear to be large, but without pre-harvest measurements, no trends can be identified. In addition, variability may be obscuring any differences between the sites.

White Spruce Foliar Properties

On Site 2, foliar SO_4-S was significantly lower in planted white spruce than on Site 1 (Table 9); and foliar Cu, Zn and Al were significantly greater. No other white spruce foliar properties varied significantly between the two sites.

Foliar N concentrations (1.39 and 1.51%) of white spruce seedlings on clearcuts in Alaska were greater than those (1.16%) of seedlings in adjacent undisturbed white spruce stands (Gordon and Van Cleve 1987). In this study, planted white spruce seedlings in Site 1 (relatively undisturbed) actually had greater concentrations of foliar N (1.21 vs 1.16%) than seedlings in Site 2 (a clearcut). Results of the Alaska study suggest that the higher soil temperatures of the clearcut enhance decomposition of organic matter, increasing nutrient availability (Gordon and Van Cleve 1987). The limited temperature monitoring of this study did not show major soil temperature differences between Sites 1 and 2 in 1989. Soil sampling indicated lower levels of mineralizable N in the forest floor of Site 2. Differences in vegetative cover, particularly the aspen regeneration of this study, suggest that nutrient uptake by competing vegetation may be an important factor.

Forest floor or mineral soil SO_4-S showed no significant differences (although differences could be obscured by the relatively high variability of SO_4-S). No soil analyses for soil Cu, Zn and Al were done and it is unlikely that they would be informative.

Potential reasons for these variations in foliar properties include the interactions between: 1) nutrient availability under different environmental conditions; 2) competition for nutrients; and 3) greater total uptake by the new vegetative growth on Site 2.

TABLE 9. Mean and standard deviation (in brackets) of selected white spruce foliar properties (mg/100 needles) for Sites 1 (residual aspen present) and 2 (no residual aspen) (n=3)[1]

	Foliar properties (mg/100 needles)				
Site	**N**	**SO_4-S**	**Cu**	**Zn**	**Al**
1	286.2a	1.554a	0.063a	1.424a	1.461a
	(20.6)	(0.043)	(0.012)	(0.166)	(0.050)
2	283.7a	1.051b	0.099b	1.688b	1.984b
	(6.7)	(0.122)	(0.028)	(0.017)	(0.118)

[1] Values within columns followed by the same letter do not differ significantly (Mann-Whitney U Test, p =0 .05).

The differences in SO_4-S status are particularly interesting for two reasons:

1. Foliar nutrient analysis identified S as a potentially limiting nutrient if the more severe N deficiency were alleviated.
2. Foliar Cu, Zn and Al were all greater in Site 2, which was the opposite of SO_4-S.

One possible explanation is that competition for SO_4-S may be more severe on Site 2. The vigorously regenerating aspen are using an extensive well-established root system, and herbaceous cover was greater on Site 2. Planted white spruce seedlings with relatively limited root systems may be less able to compete for SO_4-S.

Seedling Performance

Assessments of seedling performance may have been confounded by the mix of stock types planted within the block, and the possible effects of planting done by inexperienced people.

Of the seedling characteristics measured, total height of all living planted seedlings was the only characteristic significantly different between sites (Table 10). Average total height of planted white spruce in Site 2 was 74.5 cm, compared to 61.5 cm in Site 1 (Fig. 14). All other characteristics measured (Table 10) did not vary significantly between sites. Within-site variation, however, was high for all characteristics measured (Table 10). Under the factor, average leader increment for all living seedlings, only two replicate plots on Site 2 met the standard of a 15-cm leader in 1989 (Fig. 14).

TABLE 10. Mean and standard deviation (in brackets) for white spruce seedling characteristics measured on all living seedlings and "acceptable" seedlings on Sites 1 and 2

	All seedlings[a]		Acceptable seedlings	
Characteristic	Site 1 (n=138)	Site 2 (n=147)	Site 1 (n=47)	Site 2 (n=62)
Total height (cm)	61.5* (21.1)	74.5 (27.8)	83.1 (16.4)	94.9 (22.7)
Leader height (cm)	12.4 (8.7)	15.5 (10.1)	21.6 (6.1)	23.1 (7.6)
Previous leader height (cm)	8.2 (5.9)	11.5 (7.6)	14.1 (5.2)	16.1 (7.4)
"Crown" diameter (cm)	30.6 (11.4)	30.3 (12.3)	41.4 (9.0)	38.8 (10.5)
Buds on leader	11.1 (6.9)	13.0 (8.5)	18.1 (4.9)	19.2 (6.1)
Root collar diameter (mm)	10.0 (2.7)	10.9 (1.3)	12.3 (2.3)	12.9 (3.4)
Competition index	2199* (2102)	3838 (3039)	2273 (2144)	3409 (2346)

[a] (*) Significantly different (0.05 level) from Site 2 values for all seedlings.

The same statistical analyses were done with a subset of seedlings that were considered to have "acceptable" form and lacked any obvious defects, such as forking, previous leader mortality, and galls. No significant difference was found between the two sites for any of the characteristics measured on acceptable seedlings. On a per-hectare basis, the number of acceptable seedlings ranged from 200 to 625. No significant difference in the number of acceptable seedlings existed between the two sites. The lowest number was in the replicate plot which had the greatest number of aspen residuals (450 per hectare). On average, all acceptable trees met the 15-cm leader increment standard in 1989 (Fig. 15).

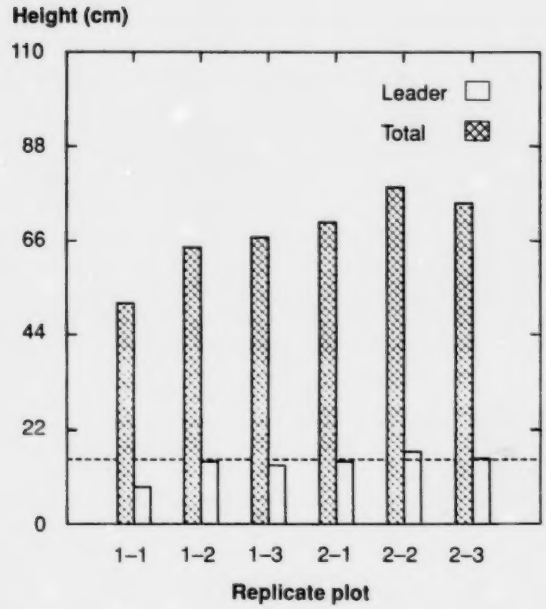

FIGURE 14. Average total height and current leader increment for all white spruce seedlings on Sites 1 and 2 in 1989.

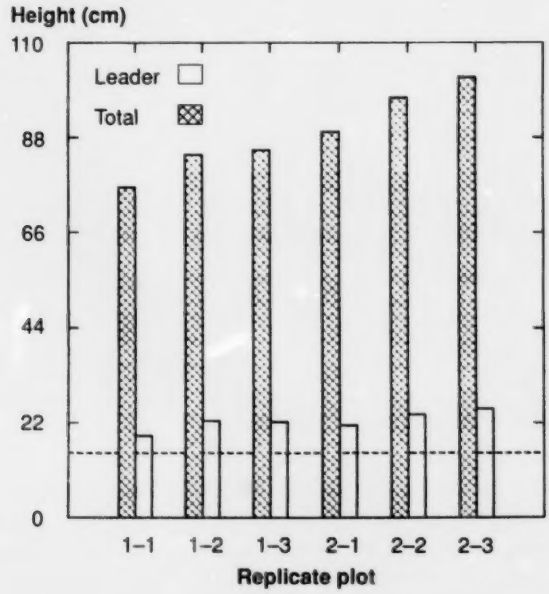

FIGURE 15. Average total height and current leader increment for "acceptable" white spruce seedlings on Sites 1 and 2 in 1989.

For all living planted seedlings, competition index values were significantly greater on Site 2 (Table 10). When the acceptable seedlings were compared, Site 2 tended to have greater competition and greater total height (Fig. 16, Table 10), but the differences were not statistically significant. The acceptable seedlings on Site 2 tended to have lower competition index values than the average for all seedlings (Fig. 16, Table 10). The study design could not separate effects of competition from the effects of microsites which allowed trees to grow above vegetative competition.

At present, no guidelines have been established for assessing whether competition index values measured for these sites were at unacceptable levels for the BWBS. The number of aspen regeneration in Site 2 (11 000–15 000 stems per hectare; Table 3) were not exceptionally high, nor was the amount of *Calamagrostis* cover very great.

Only one measurement for photosynthetically active radiation (PAR) was completed for all sample seedlings on both Sites 1 and 2 during 1989. There was no significant difference in PAR values between Sites 1 and 2 (Fig. 17). Within-plot variability was very high (Fig. 17).

As would be expected, seedlings with greater vegetative competition had lower values for PAR. There was a significant negative correlation between PAR and competition index values (-.504) for sample seedlings on Site 2. On Site 1, the correlation between PAR and competition index was also negative (-.321) but not statistically significant. The shading from residual trees on Site 1 would not be directly related to competition index values, but would influence PAR, depending on sun angle at the time of measurement. For Site 2, a greater amount of sunlight would have been blocked by adjacent vegetation, resulting in a higher correlation.

Tappeiner *et al.* (1987) reported that bud production on leaders of Douglas-fir was more responsive to levels of competition than was leader growth or growth in stem diameter. In 1989, no significant correlations were found between numbers of buds and any other characteristics measured for white spruce on Sites 1 and 2. However, acceptable seedlings did have greater numbers of buds compared to the average for all seedlings (Table 10).

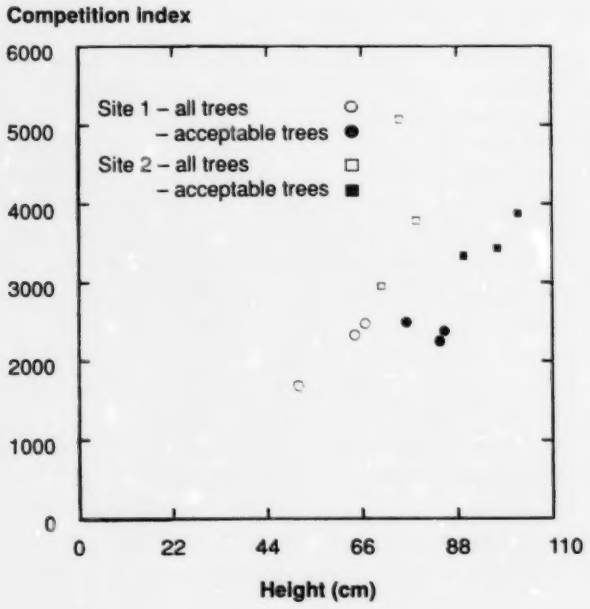

FIGURE 16. Competition index and total height for all seedlings and "acceptable" white spruce seedlings on Sites 1 and 2 during 1989.

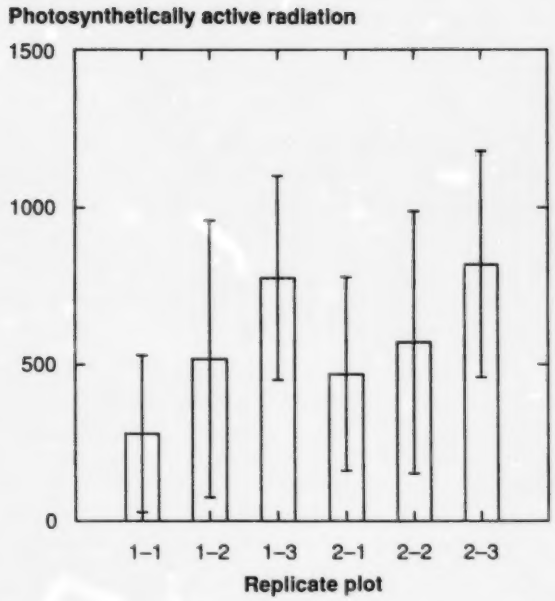

FIGURE 17. Photosynthetically active radiation for white spruce seedlings on Sites 1 and 2 on July 12,1989.

WHITE SPRUCE ESTABLISHMENT AND GROWTH UNDER *POPULUS*

Factors Influencing White Spruce Establishment

Boreal forest fire studies (e.g., Dyrness *et al.* 1986) and an examination of stands in the Fort Nelson District[1] have described two typical patterns of white spruce establishment when it is associated with aspen. These patterns depend on fire intensity, site characteristics, and seed sources. A relatively severe fire which creates mineral soil seedbeds will allow white spruce to establish by seed at the same time that aspen are regenerating from root suckers. The resulting mixed stand would have very similar ages. A second common scenario follows a less severe fire which does not create mineral soil seedbeds suitable for white spruce. Twenty years or more after the disturbance, when vegetative competition has decreased and suitable microsites are available, the white spruce will begin establishing itself under the aspen. An examination of increment cores at stump height (30 cm) shows that white spruce did not begin invading Site 3 until the aspen was approximately 50 years old.

Succession on alluvial sites near Fort Nelson has been described by Annas (1977), and is similar to other descriptions from the Northwest Territories (Jeffrey 1964). Herbaceous plants and willows are the first plants to establish on the alluvial material. A willow - alder complex then develops, associated with or followed by an influx of balsam poplar. The balsam poplar eventually overtops the willows and alder. At some point, white spruce invades the site and eventually overtops the balsam poplar, which then becomes decadent and dies out.

The three criteria for successful natural seeding are: 1) a source of viable seed; 2) a suitable seedbed; and 3) a suitable environment for germination and seedling establishment (Daniel *et al.* 1979).

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[1] Parminter, J. 1983. Fire-ecological relationships for the biogeoclimatic zones and subzones of the Fort Nelson Timber Supply Area: summary report. B.C. Min. For., Northern Fire Ecology Project. Unpublished report.

Good white spruce seed years generally occur every 10–12 years in northern British Columbia, with minor or medium crops in between.[2] Climatic effects are the major influence on seed production. Seed consumption by animals can prevent adequate regeneration, even in good seed years (Stiell 1976).

The most favorable seedbeds for white spruce are mineral soil, mixed soil and humus, and decayed wood (Stiell 1976). White spruce, tamarack, white birch, balsam poplar, and aspen all experience the most successful germination and early seedling growth in exposed mineral soil or seedbeds that have a small component of organic matter (Zasada 1986).

While white spruce can establish on litter, moss, and rotten wood, each of these organic substrates will vary in depth and their ability to support germination and seedling establishment (Zasada 1986). These organic seedbeds tend to be best under shaded conditions where surface drying is reduced (Zasada 1986). Initial survival of white spruce depends largely on an uninterrupted adequate supply of moisture (Sutton 1969).

In white spruce stands on alluvial sites, white spruce seedling distribution tends to be aggregated because the surface and microsites most suitable for invasion by the seedling are aggregated (Zasada 1986). The raised microtopographical positions most favorable to white spruce seedlings are found on rotted wood, windthrown mounds, and pit edges. On Site 6, for example, white spruce regeneration was concentrated on raised microsites. Burial or damage to conifer seedlings by annual litterfall of deciduous species is less likely on such raised microsites.

The important determinants of surface conditions for seed reproduction are dynamic on two time scales (Zasada 1986): 1) a short-term basis (daily, weekly, or less) as moisture and temperature fluctuate; and 2) a long-term basis as the developing vegetation and its debris changes microsite conditions and resource availability.

Post-establishment Interactions

One of the benefits attributed to aspen for spruce establishment on upland sites is partial shading. White spruce is shade tolerant, and can maintain maximum height growth with 45% full light (Johnson 1986). Stiell (1976) believed that the value of shade was debatable, although it might prevent excessive temperatures. Reduced evapotranspiration and avoidance of lethal soil surface temperatures were the beneficial effects of shading suggested by Brix (1972).

In the Lake States, white spruce planted under 30% shade from aspen or white birch for the first 10–12 years were usually taller than those planted in open areas, possibly because of the reduced incidence of frost damage (Russell 1963, as cited by Rausher 1984). Positive effects of partial shading for 3- or 4-year-old white spruce were attributed to protecting the seedling from insect attack without affecting height growth (Olson and Perala 1981, as cited by Rausher 1984).

Shade produced by shrubs and herbs may be beneficial during germination of white spruce seed and first-year growth of white spruce seedlings, but presence of these was considered detrimental for later development (Zasada 1972). Non-living or overstory shade production was considered as most desirable for white spruce seedling establishment (Zasada 1972). It is generally recognized that once the white spruce seedling is established, reductions in light intensity are detrimental (Johnson 1986).

Studies have recently begun in young stands with mixed regeneration of aspen and lodgepole pine in Alberta (S. Navratil, pers. comm., 1990, Forestry Canada). Preliminary results suggest that the competition thresholds vary depending on which growth variable is being considered, and on the age of the crop tree. For example, with 10- to 16-year-old lodgepole pine, height growth was reduced by 20% when aspen cover reached 50–70%. Negative effects on radial growth were found when aspen cover was 40% or greater. Relationships between competition and growth for the 4- to 8-year-old age class of lodgepole pine were not well defined (Navratil *et al.* 1990). Future analysis will attempt to quantify growth losses and develop a framework for release prescriptions.

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[2] Parminter, J. 1983.

Rausher (1984, citing Olson and Perala unpublished) suggests that white spruce is more sensitive to root competition when it is growing in clay soils, possibly because of limited soil moisture and aeration. The predominance of white spruce roots in the forest floor above aspen roots, as was observed on Site 3 of this study, may be a competitive advantage for white spruce (Strong and LaRoi 1983, 1985).

White Spruce Response to Release Treatments

Recent remeasurements of white spruce release trials in Saskatchewan and Manitoba were reported by Yang (1989). The total volume increments of white spruce after removal of the aspen overstory ranged from 24 to 304% above that of the untreated controls (Fig. 18; Yang 1989). Periodic annual total volume increment increased 93%, from 2.50 m^3/ha per year for control stands to 4.83 m^3/ha per year for released stands. The release treatment substantially improved spruce total stand volume in all locations. The largest dbh improvements occurred when the released spruce were between 15 and 40 years old. White spruce residuals of 690–840 stems per hectare released at 20–40 years of age would provide adequate merchantable yields at rotation age (Yang 1989).

Johnson (1986) has written preliminary guidelines for release treatment of white spruce for mixed stands in Manitoba. These guidelines provide an excellent starting point for the development of similar guidelines for the Fort Nelson District. To test them in this study, Sites 4 and 5 were assessed according to Johnson (1986).

Site 4 had 800–950 aspen stems per hectare, at an average of 80 years old (Table 3). White spruce potential crop trees ranged from 1000–1200 stems per hectare, ranging in age from 40 to 60 years. The appropriate key from Johnson (1986) was as follows:

A. Spruce understory 500 stems per hectare, treatment not recommended
B. Spruce understory 1000–2000 stems per hectare
C. Windfall risk high
D. Windfall risk low
E. Commercial logging of aspen will occur
F. Commercial logging of aspen will not occur

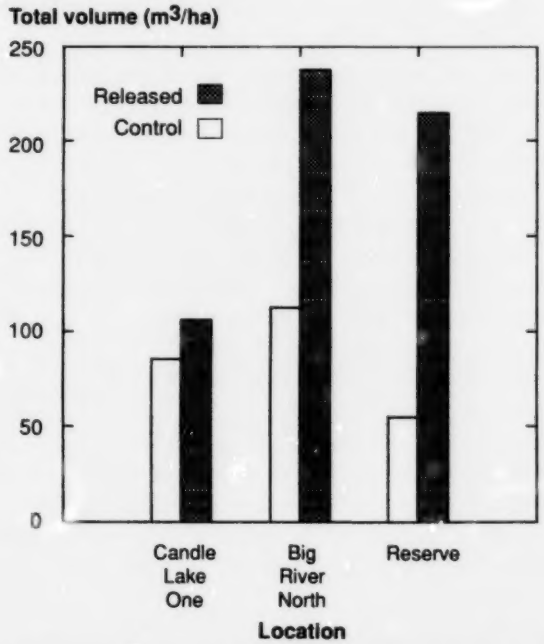

FIGURE 18. Thirty-year total volume increment for three white spruce stands in Saskatchewan (Yang 1989).

Since the aspen are of commercial size, Site 4 could be a combination of B, C and E. Treatment priority for such stands was considered low to medium (Johnson 1986). Windfall risk was high. Special logging precautions might be required, both to reduce windfall risk and to preserve the spruce understory. Local experience in harvesting methods to reduce damage to understory spruce could also be tested on Site 4.

Site 5 had 2900–4300 aspen stems per hectare averaging 45 years old (Table 3). White spruce potential crop trees ranged from 750 to 1150 stems per hectare, from 25 to 35 years of age, and from 5 to 7m in height. The appropriate key from Johnson (1986) was as follows:

A. Spruce understory 600 stems per hectare, treatment not recommended
B. Spruce understory 1200–2500 stems per hectare
C. Windfall risk high
D. Windfall risk low
E. Spruce understory averages < 2.44 m in height
F. Spruce understory averages > 2.44 m in height

Scenario B, D and F appeared to be most appropriate. Risks and problems with releasing such stands were considered minimal, and treatment priority high. A variety of potential chemical and manual release treatments could be employed. The white spruce stocking in this stand approaches low levels where the release treatment is not recommended. As well, since Site 5 was on a well-drained coarse-textured soil, moisture deficiencies may limit growth response.

Large areas of aspen with spruce understories exist in the Fort Nelson District. Classification tools to aid in the identification of ecosystems are available and can be used to consider site productivity potential. Release guidelines could be developed based on Johnson (1986) and other current research on mixedwood management (Navratil *et al.* 1989a). Preservation of the spruce understory during harvesting is being studied by Brace (1989).

All of these techniques need to be examined under local conditions, but they provide an excellent starting point to develop integrated silvicultural strategies for hardwood stands with spruce understories in the Fort Nelson District.

BACKLOG REFORESTATION STRATEGIES

Three general strategies for reforesting backlog areas in the Fort Nelson District are discussed below: 1) re-establishment of white spruce; 2) re-establishment of mixedwood; and 3) re-establishment of hardwood. For each strategy it was assumed that rapid regeneration of these backlog sites with commercial tree species was the primary objective, and that further delays in regeneration and rotation were unacceptable. Competition from *Calamagrostis canadensis* and appropriate conifer planting stock are also discussed.

Issues affecting the choice of backlog reforestation strategies have ecological, policy, and regulation considerations, but only the ecological considerations will be discussed here. Choice of the appropriate ecological strategy must consider both site productivity potential and regeneration performance (Navratil *et al.* 1989b).

Re-establishment of White Spruce

Establishing a white spruce plantation on backlog sites has been a major problem in the boreal forest and has received a great deal of attention during the most recent federal-provincial forestry agreements in all four western provinces. Experimental and operational experience in selecting appropriate site preparation treatments has increased and is documented in various publications (e.g., Coates and Haeussler 1987) and available through extension activities. Characterization of typical mixedwood sites, as done in this study, will help Fort Nelson District staff evaluate potential techniques from other areas.

A program of site preparation and planting would be required to re-establish conifers on many backlog areas in the Fort Nelson District. Restrictions on the use of mechanical site preparation (e.g., winter-only access, limited equipment availability) may require innovative use of prescribed fire, chemicals, and other treatments to control competing vegetation.

Competing vegetation is the major consideration for conifer re-establishment on backlog sites. Moisture and nutrient conditions are usually better than average. The form of site preparation used should create a microsite that will be free of competing vegetation for 2 or 3 years while the seedling is becoming established. Follow-up control of competing vegetation will almost certainly be required, and should be planned for.

Frost heaving is a major cause of mortality for seedlings planted in exposed mineral soil that is created by some forms of mechanical site preparation. Seedlings planted in fine-textured soils, which are common in the Fort Nelson Forest District (Valentine 1971), are particularly at risk.

Direct seeding is unlikely to be a viable option for backlog sites in Fort Nelson, where competitive vegetation is well established. It has been considered viable in the Yukon (Gardner 1983) and Alaska (Putnam and Zasada 1986), where access to sites during the growing season was difficult and expensive, and very limited quantities of planting stock were available. Putnam and Zasada (1986) summarized the basic requirements for successful direct seeding as follows: 1) that adequate site preparation was used; 2) that seeds were applied as soon as possible after harvesting and site preparation to avoid vegetative competition; and 3) that sufficient amounts of high quality seed were applied.

Mixedwood

Appropriate management techniques for mixed stands of deciduous and coniferous trees are still being developed in Western Canada. Results are preliminary and operational experience is relatively limited (Samoil 1988; Shortreid 1991).

Site preparation and conifer establishment methods could be used (e.g., prescribed burning and planting of white spruce), if deciduous regeneration were accepted for stocking assessments. Silvicultural techniques appropriate for managing such stands are undefined at present.

Where aspen or balsam poplar residuals remain in sufficient numbers to suppress grass and shrub competition, raw underplanting of white spruce might be an option. Careful selection of microsites to favor the white spruce would be needed. Operational underplanting of aspen residuals using white spruce with no site preparation other than screefing by planters has been done since 1986 near Whitecourt, Alberta (D. D'Amico, pers. comm., 1990, Blue Ridge Lumber Ltd.). Plots monitored 3 years after planting showed over 93% survival. White spruce leader increments were considered satisfactory. However, planting immediately after logging is considered crucial for the success of this technique (D. D'Amico, pers. comm., 1990).

Hardwood

Where other considerations are favorable, regeneration of backlog sites to hardwoods may be easier to accomplish than conifer regeneration. Height growth of aspen and balsam poplar is usually rapid enough to overtop grass competition after two or three growing seasons.

On backlog sites, the presence of a thick forest floor, a rise in water table following harvesting, low soil temperatures, low numbers of aspen residuals, and invasion of shrub species would all act to create a relatively poor environment for aspen suckering (Navratil *et al.* 1989b). Raising soil temperatures to stimulate suckering is probably more critical than carbohydrate reserves in ensuring sufficient hardwood regeneration at northern latitudes (Schier 1976).

Felling or knockdown of aspen residuals, combined with winter shearing of shrubs, would be one possible treatment for hardwood regeneration. The net effect would be to relieve aspen lateral roots from chemical inhibition of suckering, to remove any overstory shading, to achieve the greatest amount of insolation and soil warming possible, and to set back competing shrub species. The estimated numbers of well-distributed aspen residuals required to stock a site fully ranges from 25 to 125 per hectare (Doucet 1989; Navratil *et al.* 1989b).

The number of well-distributed aspen suckers considered to be adequate regeneration varies in the literature (Davidson *et al.* 1988; Peterson *et al.* 1989). Locally generated guidelines need to be developed from productive aspen-dominated ecosystems. Steneker (1976) considered 6000 well-distributed aspen stems per hectare at year 3 to be adequate for stands managed for fiber. Initial variations in aspen sucker densities are usually reduced after periods of 10–20 years (Peterson *et al.* 1989).

For alluvial or upland sites where balsam poplar is the preferred or dominant hardwood species, similar techniques are appropriate. Balsam poplar can reproduce by seed and vegetatively from basal sprouting, layering, root suckering, and regrowth from detached vegetative parts such as stem and root segments (Zasada 1986). These responses will vary with site, and with severity and type of disturbance. Dormant season harvesting was most desirable for balsam poplar regeneration on alluvial sites in Alaska (Zasada *et al.* 1981).

A planting option for hardwood on backlog sites may not be too distant. Triploid aspen and superior birch clones are planted in Finland, and are being grown at the B.C. Ministry of Forests Kalamalka Station in Vernon. Hybrid poplar trials in northeastern British Columbia have only recently been established (J. Revel, pers. comm., 1990, B.C. Ministry of Forests). Crosses using superior local genotypes may be the best route to introduce genetic gains for poplar in northeastern British Columbia (M. Carlson, pers. comm., 1989, B.C. Ministry of Forests).

Calamagrostis Considerations

The following discussion of *Calamagrostis canadensis* highlights aspects of the species' autecology which have obvious management implications for backlog reforestation. This discussion is largely based on results of recent research conducted by Dr. V. Lieffers, University of Alberta.

Calamagrostis canadensis (bluejoint) is often the major competitor with seedlings on backlog sites in northeastern British Columbia. Knowledge of its autecology is relatively limited; what is known has been summarized by Haeussler and Coates (1986). With this limited information, predicting the response of bluejoint to forest management activities is often difficult.

Bluejoint spreads through seed dissemination and by expansion of rhizomes. Invasion of disturbed sites by seed may be more important than is realized (V. Lieffers, pers. comm., 1990). Genetic variability of bluejoint populations on recently disturbed areas is high, which indicates that the plants were established by seed. Relative response of bluejoint to different seedbeds — for example, a disturbed forest floor vs a burned forest floor — is not clearly understood.

In greenhouse trials, under optimum conditions, bluejoint seedlings are hardy and grow rapidly within 2 weeks after germination. After 6 weeks in a greenhouse, a dense sward of grass up to 30 cm high can be established (V. Lieffers, pers. comm., 1990). Bluejoint appears to have the potential to establish a vigorous, hardy stand of plants the same year as it germinates from seed.

Rhizomes are predominantly in the lower layers of the forest floor, near the mineral soil interface. They are also found in the mineral soil. One management implication of rhizome distribution is that even a severe burn, or any other site treatment that removed all the surface organic material, would not necessarily eliminate all rhizomes.

The possible effects of prescribed burns on bluejoint are unclear. Burning on mesic sites may create conditions which allow competitors such as fireweed (*Epilobium angustifolium*) to establish (V. Lieffers, pers. comm., 1990).

Bluejoint litter creates excellent thermal insulating conditions. A layer of dense litter with many air spaces adjacent to the ground surface is present after a few growing seasons. In northern Alberta, mineral soil thawing under a dense bluejoint sward was delayed for several weeks in spring compared to adjacent areas that lacked grass cover (V. Lieffers, pers. comm.,1990). The grass litter accumulation and insulating effects inhibited regrowth. Experimental removal of litter resulted in better carbohydrate status and more vigorous growth of bluejoint. Site preparation activities that removed grass litter or caused soil warming would likely also stimulate bluejoint.

A low, dense grass canopy can be a frost-prone environment for seedlings (Stathers 1989). The grass creates a stagnant air layer that traps cold air and allows it to continue radiative cooling. The coldest layer within the grass canopy is not at the ground surface, but nearer the densest layer of vegetation where more longwave radiative loss occurs (Stathers 1989). The dense grass stand may also create microclimatic conditions that increase frost risk and soil heat loss even more. When combined with the insulative qualities of grass litter, the microclimatic conditions may further reduce length of growing season and soil temperatures on grass-dominated sites.

Dormant buds are present all along a bluejoint rhizome. When the rhizome is cut off from aboveground plant parts, the buds are released from inhibition. The terminal bud on a rhizome is the most vigorous, and is usually the first to create an aboveground plant. This suppresses the other buds on the rhizome, though their growth potential is unimpaired, maintaining the regenerative capacity of the rhizome.

A "double-discing" treatment which brought rhizomes to the soil surface during a period of drying was the most successful mechanical control of bluejoint (V. Lieffers, pers. comm., 1990). Smaller pieces of rhizome are more easily water-stressed, which depletes their carbohydrate reserves and prevents re-establishment.

Conifer Planting Stock Appropriate For Backlog Sites

Large container white spruce stock with a stout caliper and proportionate root mass was consistently recommended for backlog reforestation (D. D'Amico, J. Kitz, J. Revel, pers. comms.). Container stock has significantly greater leader increments 3 years after planting in regeneration performance monitoring trials in Alberta (J. Kitz, pers. comm., 1990, Alberta Dep. of Forestry, Lands and Wildlife). White spruce bareroot (3-0, 2-0), plug + 1, and Spencer-Lemaire Root trainers (40, 65, 90 and 175 cc volume) were the stock types compared.

The minimum requirement for a backlog site was felt to be white spruce 2+0 PSB 313 (D. D'Amico, pers. comm., 1990). A stout caliper (4–6 mm) was considered to be a key characteristic (D. D'Amico, pers. comm., 1990; J. Revel, pers. comm., 1990); tall stock, without a good caliper, was susceptible to snowpress or other damage. Larger stock, such as PSB 2+0 415, with a balanced root mass and caliper of 4–6 mm, were considered to be preferable to PSB 2+0 313 stock for planting on backlog sites.

SUMMARY AND CONCLUSIONS

The study sites represent a range of site conditions and successional stages of mixed white spruce — *Populus* stands in the Fort Nelson Forest District. Quantitative characterization of representative ecosystems will allow better assessment of forest management activities and technology transfer in the future.

Interrelationships between soil temperature, moisture, and organic matter quality may be major determinants of nutrient availability. This was best demonstrated by Site 5, which had coarse-textured soils with inherently lower fertility, but the highest foliar nitrogen content (mg/100 needles) for white spruce.

White spruce foliar N and S were below recommended adequate levels for all sites. These results were similar to those from more widespread sampling of white spruce plantations in the Prince George and Cariboo Forest Regions.

Environmental conditions and growth performance of white spruce planted under a residual aspen canopy (Site 1) were compared with those characteristics for white spruce planted in adjacent areas with no aspen residuals (Site 2). The number and severity of potential frost events were greater where no aspen residuals were present (Site 2). In 1989, however, no frost damage was observed on planted white spruce on either site.

Site 2 had greater degree-day accumulations in the forest floor than did Site 1, but slightly lower accumulations in the upper mineral soil. These differences may have been due to soil variability, but without replicated sampling no statistical examinations could be done.

Forest floor moisture monitoring over the 1989 growing season indicated that Site 2 had greater moisture content in May and June, and less moisture than Site 1 for the remainder of the growing season. More detailed examination of the soil moisture regime is required to assess the importance of these differences.

Nutrient uptake by aspen regeneration may be the cause of lower forest floor mineralizable N and exchangeable K on Site 2. No significant differences in white spruce foliar content (expressed as mg/100 needles) occurred between Sites 1 and 2. The greater foliar nutrient concentrations in planted white spruce on Site 1 may have reflected a combination of less foliar biomass and less competition for available nutrients.

Of all properties measured, total height and vegetative competition were greater for white spruce seedlings on Site 2 where no aspen residuals were present. The measurements suggest that aspen residuals reduced the growth of planted white spruce as well as the growth of potential competitors to the white spruce on Site 1. These results are not conclusive, however, about the success or failure of planting under aspen residuals. The possibility still exists that as the aspen residuals die, release of the white spruce will occur. Closer examination of this practise is required, and should include study of both the silvicultural implications and economic considerations.

Patterns of white spruce establishment observed on these sites were similar to those described in the literature. On upland ecosystems, successful white spruce establishment is usually the result of good seed years followed by favorable climatic conditions for germination and seedling establishment on suitable microsites. Fire, windthrow, and tree mortality vary the number and distribution of suitable microsites. Several age classes of white spruce were found on Sites 3, 4 and 5. Each age class probably coincided with good establishment years for white spruce. On alluvial ecosystems, major flooding events that leave silt deposits may create extensive seedbeds (Site 6). Microsites created by windthrow and dead wood are important in later successional communities which are rarely flooded.

The natural establishment of white spruce has two important management implications:

1. Careful attention to microsites may greatly improve white spruce seedling survival and performance, particularly where site preparation has left existing microsites intact (e.g., prescribed fire) or created new ones (e.g., mechanical site preparation).
2. Planting large white spruce container stock would avoid the requirements of direct seeding methods, which are favorable climatic conditions for germination and initial seedling establishment.

Potential volume gains ranging from 24 to 305% for release of white spruce were identified in the literature. Sites 4 and 5 could be used in future white spruce release experiments. Experience based on local trials is needed to develop silvicultural guidelines for management of stands with white spruce understories.

Establishment of conifers on backlog areas, where grass and shrub competition is well established, would require appropriate site preparation to help in controlling vegetation. Exposure of mineral soil in site preparation increases the hazard of frost heaving, and improves site conditions for competitors, particularly grasses. Where sufficient aspen or balsam poplar residuals exist, knockdown and shearing treatments may fully stock backlog sites to hardwoods. On some sites, attempts to regenerate conifers will create young mixedwood stands. Management techniques for such stands are currently being developed.

Recent studies in Alberta and the advice of experienced foresters are consistent in recommending large white spruce container stock (e.g., PSB 415) with a 4- to 6-mm caliper for planting on backlog sites.

RESEARCH AND EXTENSION NEEDS

Continued temperature and moisture monitoring on all six sites would provide long-term data to improve characterization of environmental conditions. Plant-available water status of each site should be determined through measurements such as hydraulic conductivity of undisturbed soil samples.

Site productivity is strongly affected by interactions between temperature, moisture, and organic matter quality. Local trials of stand management techniques should include site characterization and monitoring of these factors for pre-harvest, harvest, and post-harvest conditions.

Seedling growth performance on Sites 1 and 2 should be monitored in another 3–5 years and at future intervals. Any release effect on the white spruce after mortality of the residual aspen would be of particular interest.

Underplanting aspen residuals with white spruce needs systematic, long-term study. The initial poor growth of underplanted white spruce may be outweighed by long-term growth performance, or other considerations. In the Fort Nelson District, backlog areas should be identified where this technique may be feasible. Any underplanting trials should be linked to type of planting stock. Conifer planting stock requirements for underplanting may be different from those now available.

Sites 4 and 5 could be used for aspen overstory removal trials, provided undisturbed portions of stands are left as controls. Site 4 could also provide an opportunity for testing logging methods to preserve white spruce understories. The contrasting environments of Sites 4 and 5 would be useful in identifying important site factors (e.g., moisture regime, rooting depth, microclimate, soil temperature) for predicting response to aspen overstory removal.

Preliminary conifer release guidelines could be developed for the Fort Nelson District from existing information sources identified in this report. Comprehensive, site-specific guidelines would have to include policy and economic considerations, as well as ecological factors. These preliminary guidelines could be improved with knowledge gained from local trials.

The relatively low (< 15 000 stems per hectare) aspen regeneration of Site 2 after minimal site disturbance suggests that the combination of thick forest floor and cold moist soils has reduced aspen suckering ability. Regeneration of aspen after harvesting should be carefully documented in terms of ecosystems, amount of disturbance, and season of harvest to aid in predicting aspen regeneration and in determining local stocking standards for the Fort Nelson District.

Response of *Calamagrostis canadensis* to forest management practises, particularly backlog reforestation techniques, is an ongoing research need. Research on *C. canadensis* could focus on: 1) responses to prescribed burns, particularly the importance of seed sources vs vegetative establishment, and the rate of recovery of existing plants; 2) competitive interactions with other species (shrubs and herbs); and 3) seedbed preferences.

Trials established in the 1950's of white spruce release from aspen overstories, and of white spruce regeneration under different silvicultural regimes (shelterwood, seed tree, etc.), are located near Lesser Slave Lake. White spruce has been planted operationally under aspen residuals since 1984 near Whitecourt by Blue Ridge Lumber. Harvesting systems to preserve the white spruce understory have been tested near Whitecourt, Hinton, and Drayton Valley (L. Brace, pers. comm., 1990, Forestry Canada, Edmonton). A short field tour linking a number of these sites would be an excellent extension project for mixedwood management in the BWBS.

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